Composition, Texture and Diagenesis of Carbonate Sediments: Effects on Benthic Optical Properties

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LONG-TERM GOAL

Our long-range objective is to understand how physical, chemical and biological characteristics of bottom sediment affect the optical properties of the shallow sea floor. Of particular interest is the identification of sedimentological parameters that can be resolved using optical methods of remote sensing. Our research focuses on carbonate sediments.

OBJECTIVES

Specific objectives are: (1) to establish correlations between compositional and textural (e.g. size, shape, surface roughness, density, and packing) parameters, benthic microbial communities, and spectral reflectance; and (2) to define optically distinct sediment types based on sediment reflectance and water-leaving radiance from spectral radiometer buoys and aircraft sensors. This work is part of ONR's program on Coastal Benthic Optical Properties (CoBOP).

APPROACH

During the past four years, we have studied the optical properties of shallow marine carbonate sediments in the vicinity of Lee Stocking Island (LSI), Bahamas. We have been involved in three, successful CoBOP field campaigns at LSI (May 1998, May 1999, May 2000). Results to date, which will be integrated with studies by a variety of other CoBOP investigators, include sedimentological analyses, spectral reflectance of sediment cores, and hyperspectral tethered spectral radiometer buoy (HTSRB) measurements. We returned to LSI in June 2001 to measure reflectance of additional bottom types and bathymetry in areas previously imaged with NRL's Portable Hyperspectral Imager for Low Light Spectroscopy (PHILLS; Davis et al. 1999). This report focuses on data collected in 2001.

During the 2001 field season, we had four primary tasks. The first was to measure the reflectance of major non-sediment bottom types, such as hard pavement, and to compare these spectra with previously measured sediment reflectance. The second task was to add the newly acquired reflectance spectra to a library used to classify hyperspectral PHILLS images. The third task was to find spectral regions that could be incorporated into future analytical bottom classification models. The fourth task

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14. ABSTRACT
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15. SUBJECT TERMS

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was to run HTSRB surveys and record bathymetry in regions of PHILLS overflights for bottom classification. Approaches for each task are summarized below.

1. Reflectance of major bottom constituents on hard pavement bottoms was measured using a "DiveSpec" underwater reflectance/fluorescence with wavelengths ranging from 400-750 nm (0.30 nm bandwidth), using 99% spectralon as reference (Mazel, 1997). Spectra were obtained for bare pavement, gorgonians (mainly light and dark varieties of *Psuedoplexaura-like species)*, hydrocorals (mainly *Millepora alcicornis)*, brown algae (mainly *Sargassum sp*.), green algae (mainly *Microdictyon marinum),* and sponges.

2. A spectral library was constructed using simulated remote sensing reflectance spectra from "Hydrolight" at variable depths using reflectance spectra of three major bottom types at LSI, sediment, seagrass, and pavement. The library included three sediment types, four densities (20-80%) of the sea grass *Thalassia testudinum*, and mixtures of typical hard-bottom pavement communities (light, medium, and dark colored). This library was used to classify PHILLS images from June 1, 1999 according to bottom type and bathymetry using a minimum distance method in the program ENVI. Classified images were georeferenced using multispectral IKONOS imagery of LSI. The results of library bathymetric classification were compared to soundings taken in June 2001. Error was calculated only from points with bathymetric sounder data as follows.

$$\%error = \left(\frac{depth_{classification} - depth_{sounder}}{depth_{sounder}} \right) * 100 \qquad (1)$$

3. Analysis of library R_{rs} spectra was conducted in order to identify wavelengths that could be used in future models to estimate bathymetry or classify sediment types. Spectra were analyzed using finite approximation to calculate 2^{nd} derivative spectra, using a 20 nm bandwidth.

4. In-water upwelling radiance (L_u) and downwelling irradiance (E_d) were measured using a Satlantic HTSRB from a small open skiff over regions with variable bottom types. Underwater video recordings were filmed in conjunction with HTSRB measurements using a Sony DCR-TRV900 digital video camera in an Aqua Video housing. Depth was recorded using a Suzuki ES2025 echo sounder with 50 kHz transducer. All measurements were tracked using GPS with Wide Area Augmentation System (WAAS) capability.

WORK COMPLETED

The June 2001 field expedition to Lee Stocking Island was highly productive. The HTSRB, which was not originally designed for towing, ran smoothly and steadily at 4 knots. Analysis of HTSRB and video data is in progress. Data from the bathymetry survey are excellent and depths have been corrected for tidal variation. Measurement of *in-situ* spectral reflectance was successful and produced high quality data for all bottom targets. Some initial results are summarized below.

RESULTS

Reflectance spectra measured in June 2001 showed that hard-bottom pavement communities have significantly different spectra than carbonate sediments (Reid 1998, 1999, 2000) (Fig. 1). Reflectance spectra of pavement communities (Fig. 1B) display a prominent dip at 675 nm, a smaller dip at around

620 nm, and a steep rise after 680 nm. The rise after 680 nm and the lack of a steep single slope from 550-680 nm distinguish pavement community spectra from sediments. Bare pavement is similar in spectral magnitude to Norman's yellow grapestone and Coconut Beach sand with film, but displays a steeper dip at 675 nm. Reflectance of sponges was almost identical to dark brown gorgonians (Fig.1B)

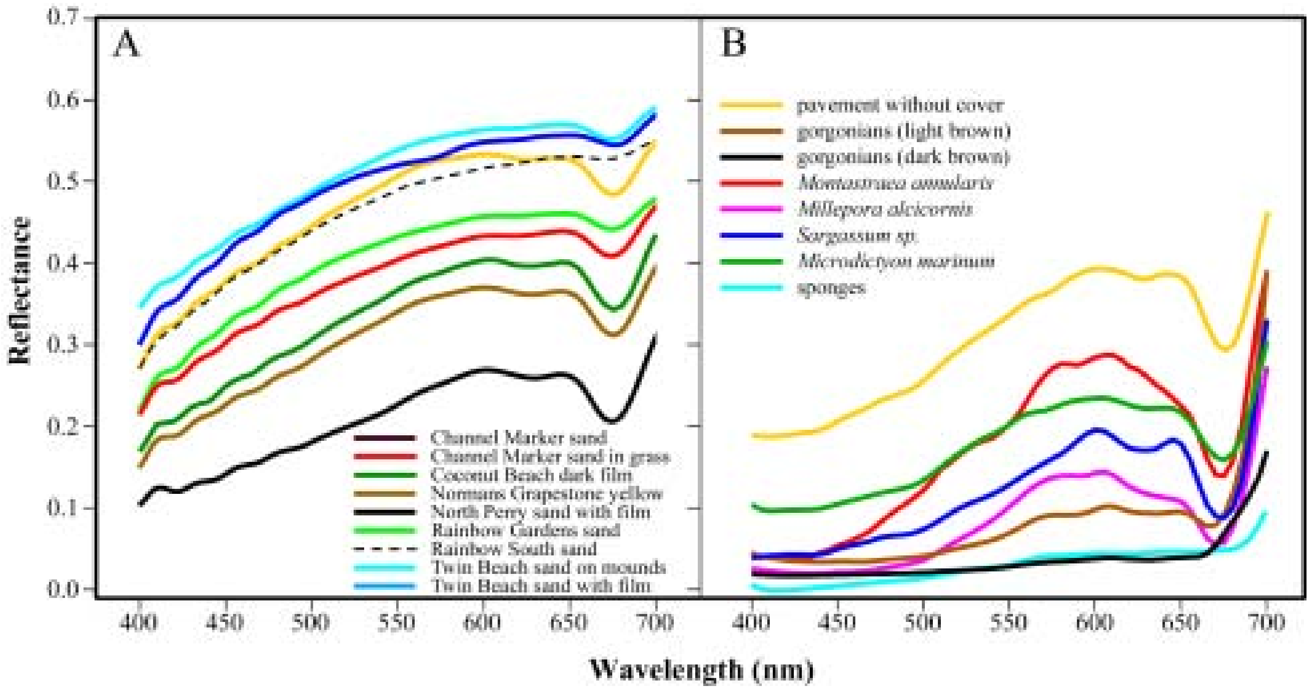

Figure 1. Comparison of reflectance from sediments and pavement bottom communities: A: sediment spectra; B: pavement community spectra.

We are currently conducting derivative analysis of June 2001 reflectance spectra. Analyses of spectra from the May 1999 and May 2000 field season indicate that absorption features of reflectance spectra can be used to distinguish bottom types and indicate pigment composition (Louchard et al. submitted; Stephens et al. submitted).

A spectral library method was developed previously (Louchard et al. 2000) to classify PHILLS images according to bottom type and bathymetry. This initial work indicated the potential usefulness of the methodology, but was constrained by a lack of reflectance measurements from pavement bottom types. The addition of pavement community bottom types into the spectral library resulted in improved classification of bottom type and bathymetry in Adderly Cut (Fig. 2A, 2C) and Channel Marker study areas (Fig. 2B, 2D). Bathymetry classified using the spectral library was shown to have a mean accuracy of 83% with standard deviation of 13%, and a median accuracy of 86% when combining results from both study areas (Louchard et al. submitted). Most of the error is associated with warping of the PHILLS image in the Channel Marker area (Figs 2B), which is an artifact associated with the camera that cannot be corrected by georeferencing. Other errors were found in both study areas at the borders of a migrating shoal and at the island shoreline, where depth changed rapidly and small georeferencing differences caused large depth errors. Shadows on slopes also resulted in spectral mismatches during library classification.

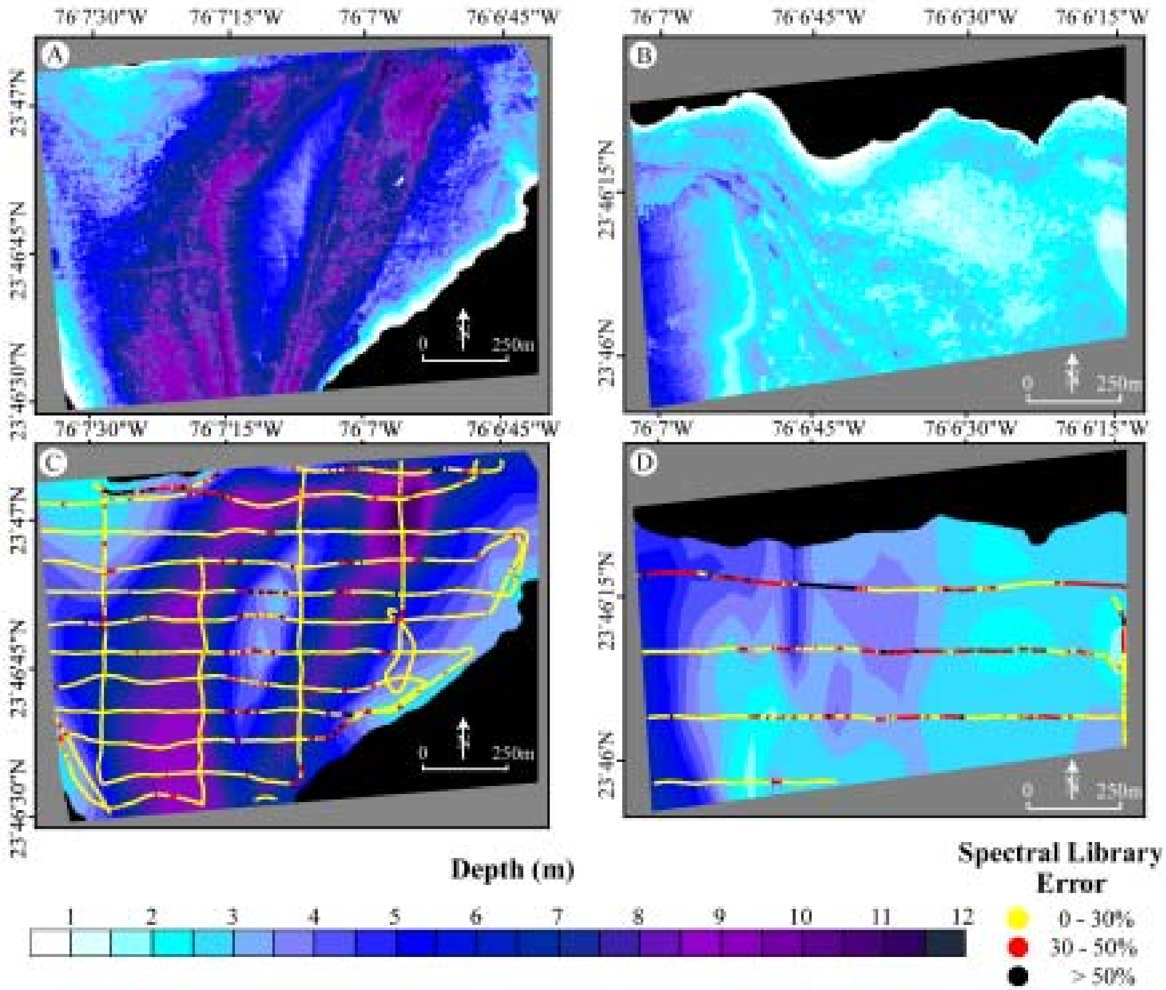

Figure 2. Comparison of bathymetry classified from spectral library (A and B) and ground truth soundings (C and D) in areas of Adderly Cut (A and C) and Channel Marker (B and D). Ground truth maps were constructed by interpolating the sounder tracks shown in C and D. Depth at each point on the sounding track was compared to spectral library depth (A and B) to calculate error in spectral library classification. Apparent warping of the shoreline in the north of B is an artifact of the PHILLS camera.

Derivative analysis of the spectral library data identified a major peak at 600 nm where the 2nd derivative magnitude varied with water depth and, to some degree, with bottom type. The variability with bottom types was minimized by dividing the 2nd derivative at 600 nm by the peak height of the 2nd derivative at 515 nm, a region that varied less with depth and more with bottom type. Peak height at 515 nm was determined using the following function:

$$Peak_{515} = \frac{d^2r}{d\lambda^2}_{515nm} - \left(\left(0.5 * \frac{d^2r}{d\lambda^2}_{547nm} \right) + 3.0 * 10 - 7 \right) \qquad (2)$$

Two distinct relationships with bathymetry emerged, one for sediment and seagrass and the other for pavement and coral (Fig.3). These relationships could be used together to determine bathymetry if bottom types were classified beforehand into either sediment/seagrass or pavement communities, possibly by using another spectral indicator.

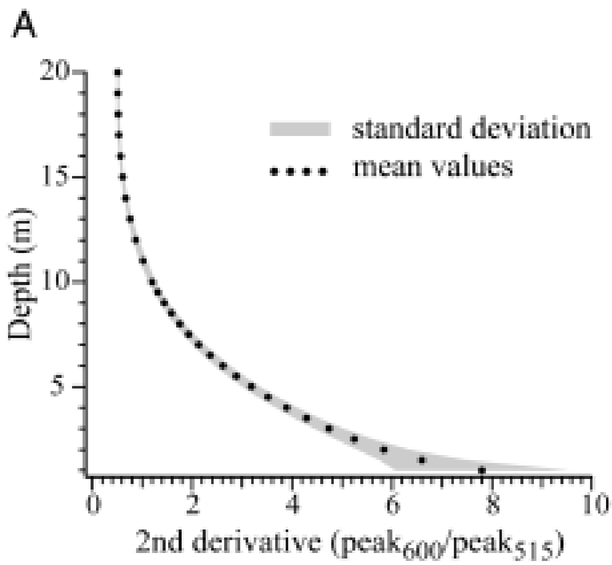

Figure 3. Mean of 2nd derivative peak ratio ($Peak_{600}/Peak_{515}$) verses depth for spectral library. A: sediment and seagrass B: pavement/coral

HTSRB data from June 2001 have been processed and are currently being analyzed using underwater video recordings as a reference. We are collaborating with personnel at Quester Tangent Corporation (QTC) to apply methods of acoustic sediment classification, such as feature extraction and multivariate statistical analysis, to optical data. HTSRB data is prepared for classification using a new software program developed by Curt Mobley to back-calculate L_u down to the bottom. The software, AO 1.0, applies an iterative process to estimate bottom reflectance from measured L_u, water depth, and water inherent optical properties.

IMPACT/APPLICATION

Our results to date indicate that spectral reflectance can be used to distinguish compositional and textural parameters of sediments and benthic microbial communities. Moreover, our data indicate that derivative spectroscopy is a potentially powerful tool for remote sensing mapping of sedimentary facies and bathymetry.

TRANSITIONS

Results from our study are being made available to other members of the CoBOP team via an FTP site at RSMAS. We are working with personnel at Quester Tangent Corp. to develop the use of ‘acoustic’ software to process HTSRB data for discrimination of optically distinct bottom types.

RELATED PROJECTS

Our work is closely related to projects of several CoBOP investigators. Methodology for measuring spectral reflectance on sediment cores was developed in collaboration with Robert Maffione (Hobi Labs). Our *in situ* reflectance measurements use the DiveSpec underwater spectrometer developed by Charles Mazel (Physical Sciences Inc.). Carol Stephens (RSMAS) is collaborating with us to quantify relationships between spectral reflectance and pigment concentrations (Stephens et al. submitted). Measurements to determine the effects of polymer on sediment reflectance were made in collaboration with Alan Decho (U. South Carolina; Decho et al. submitted). Ken Voss (U. Miami) is using our grain size data to model bi-directional reflectance distribution function (Zhang et al. submitted). We are working with Curt Davis and others at NRL on analysis of PHILLS data (Louchard et al. submitted).

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PUBLICATIONS

Peer reviewed publications acknowledging support from N000149710010:

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